4.0 Hazard Identification and Risk Assessment

This section of the plan includes a summary discussion of natural hazards that could potentially impact the Peninsula region. General hazard histories and vulnerability across the entire region, for both critical and non-critical hazards, are discussed with minimal reference to individual communities. For the purposes of mitigation planning, critical hazards are defined as those hazards for which historical data exists to document impacts that have resulted in losses to the community and its' citizens. Non-critical hazards are hazards that have occurred very infrequently or have not occurred at all in the historical data. Non-critical hazards are not considered a widespread threat resulting in significant losses of property or life. Hazard losses, historical data, and some anecdotal evidence of severity are included in this section.

Section 5 furthers the risk assessment by providing a more detailed community-specific evaluation of the critical hazards and their potential impact. Each community's risk assessment contains a summary of historical information on natural hazard losses and a detailed vulnerability assessment. The vulnerability assessment uses data available in the communities to define the hazard in terms of a metric. In this case, the metric used are the assets at risk by dollar value as established by local property assessments. The vulnerability of critical facilities is also provided. FEMA defines critical facilities as those facilities that warrant special attention in preparing for a disaster, and/or facilities that are of vital importance to maintaining citizen life, health, and safety during and/or directly after a disaster event. A final component of the risk assessment is capability assessment of existing programs and mechanisms in place to mitigate the effects of natural hazards completes the overall risk assessment. This helps determine appropriate mitigation actions by taking into account those measures that already exist.

In summary, Sections 4 and 5 identify hazards that have potential to adversely affect the jurisdictions. By quantifying potential impacts through the vulnerability analyses, and outlining existing protective measures that lessen those impacts through the capability analysis, a net vulnerability is determined. The plan's goals and objectives are then based on this net vulnerability.

4.1 Hazard Identification

The PHMPC for the Peninsula conducted a Hazard Identification study to determine which hazards threaten the planning area communities. The natural hazards identified and investigated in the Peninsula region included the following:

- Flooding
- Hurricanes & Tropical Storms
- Tornados
- Nor'easters
- Thunderstorms
- Winter Storms
- Extreme Heat
- Dam Failure
- Wildfire
- Drought
- Earthquakes
- Biological Hazards/Epidemics
- Landslides
- Expansive Soils
- Tsunamis

Historical data was collected for all hazard types. By examining the historical occurrence of each hazard, along with the impacts, the PHMPC was able to identify the critical hazards; those that pose the most significant risks to the region. This allowed the PHMPC to focus its mitigation planning efforts on those critical hazards. Prioritizing the potential natural hazards that threaten the Peninsula area required analysis of two factors: the probability that a certain type of natural hazard will affect the region and the potential extent and severity of the damage caused by that hazard. The probability of occurrence for each hazard was determined using existing technical analyses, such as the FEMA Flood Insurance Study. When data was not available, the probability was based on the history of events.

There have been 34 presidential disaster declarations in Virginia between 1953 and September 2005 (Table 4.1) with eight having direct impacts on the Peninsula.

Table 4.1 -Presidential Disaster Declarations in Virginia, 1953 –2005

Declaration Number	Month	Year	Description	Impacted Peninsula
274	August	1969	Hurricane Camille (flooding); 27 jurisdictions declared, but none on the Peninsula	
339	June	1972	Hurricane Agnes (flooding); 106 jurisdictions declared	✓
358	September	1972	Storm/Flood; Hampton and Newport News declared	✓
359	October	1972	Flood; Western, Central, Southeastern Virginia; 31 jurisdictions declared	
531	April	1977	Flash Flood; Southwestern Virginia; 16 jurisdictions declared	
543	November	1977	Flood; Southwestern Virginia; 8 jurisdictions declared	
593	July	1979	Flood; Buchanan County declared	
606	September	1979	Flood; Patrick County declared	
707	May	1984	Flood; Buchanan, Dickinson & Washington Counties declared	
755	November	1985	Flood; Western, Central Virginia; 52 jurisdictions declared	
847	October	1989	Flood; Buchanan County declared	
944	April	1992	Flood; Western Virginia; 24 jurisdictions declared	

Declaration Number	Month	Year	Description	Impacted Peninsula
1007	December	1993	Severe Storm; Tornado	
1014	February	1994	Ice Storm; Central, Western Virginia; 71 jurisdictions declared	
1021	March	1994	Ice Storm; Central, Western Virginia; 29 jurisdictions declared	
1059	June	1995	Flood; Central & Western Virginia; 24 jurisdictions declared	
1086	January	1996	Blizzard; all counties and cities in state declared.	✓
1098	January	1996	Flood; 27 jurisdictions declared	
1135	September	1996	Hurricane Fran (flooding); 88 jurisdictions declared	
1242	August	1998	Hurricane Bonnie (flooding); 5 jurisdictions declared	
1290	September	1999	Hurricane Dennis; Hampton declared	✓
1293	September	1999	Hurricane Floyd (flooding); 48 jurisdictions declared, including Peninsula communities	✓
1318	February	2000	Winter Storms; 107 jurisdictions declared, including Williamsburg, JCC and York Co	✓
1386	July	2001	Flood; Southwestern Virginia; 10 jurisdictions declared	
1392	September	2001	Pentagon Attack; 1 jurisdiction declared	
1406	March	2002	Flood; Southwestern Virginia; 10 jurisdictions declared	
1411	April/May	2002	Flood; Southwestern Virginia; 9 jurisdictions declared	
1458	February	2003	Winter Storms/Flooding; 39 jurisdictions declared	
1491	September	2003	Hurricane Isabel (winds, flooding); 100 jurisdictions declared, including Peninsula communities	✓
1502	November	2003	Flood; Southwestern Virginia; 6 jurisdictions declared	
1525	May	2004	Flood; Southwestern Virginia; 3 jurisdictions declared	
1544	September	2004	Flood; Central Virginia; 12 jurisdictions declared	
1570	October	2004	Flood; Southwestern Virginia; 10 jurisdictions declared	
3240	September	2005	Hurricane Katrina Evacuation; all Peninsula communities declared	✓

Source: VDEM and FEMA web sites.

4.1.1 Multi-Hazard Correlation

While this plan investigates individual hazard history and occurrence, it should be noted that many hazards occur simultaneously or in sequences that result in other subsequent hazards. For example, hurricanes are defined by sustained wind speed but not all hurricane damage is from wind. Heavy rains associated with these storms and storm surge generated by waters piled up on shore result in devastating flooding. The effects of natural hazards can last years after the initial damage events. High wind events blow down trees, which can increase the wildfire hazard for years to come due to an increase in downed dead or dying woody debris. In addition, uprooted trees in low-lying or typically damp areas can cause other problems. For example, the root bulb from the fallen tree can excavate large holes in the landscape, which when filled the rainwater can provide breeding grounds for mosquitoes. Another example would be the clogging of drainageways and culverts by the fallen trees.

Although the effects of storm surge can be the most devastating of a tropical system, storm surge is unlikely to occur without the existence of a tropical storm or hurricane. Therefore, storm surge is discussed below as a secondary hazard associated with tropical systems. Erosion in the Peninsula region is typically associated with nor'easters and can also be a secondary effect of sea level rise. Additional detail on the erosion hazard is included in the nor'easter and sea level rise descriptions below.

4.1.2 Flooding

Flooding is the most frequent and costly natural hazard in the United States. Approximately 80 percent of presidential disaster declarations result from natural events in which flooding is a major component. Excess water from snowmelt, rainfall, or storm surge accumulates and overflows onto adjacent floodplains—lowlands adjacent to rivers, lakes, and oceans that are subject to recurring floods. While many floodplain boundaries are mapped by FEMA's National Flood Insurance Program (NFIP), floods sometimes go beyond the mapped floodplains or change courses due to natural processes (e.g., accretion, erosion, sedimentation) or human development (e.g., filling in floodplain or floodway areas, increased imperviousness within the watershed from new development, or waterway blockage from debris including: trees, cars, trailers, and propane tanks).

There are four types of flooding in Virginia: coastal flooding, urban flooding, flash flooding, and river flooding. Due to its geographic location within the coastal plain and its rapid population growth, the Peninsula area is susceptible to all four types of flooding.

Coastal Flooding
Coastal flooding (or tidal flooding) results from higher than average tides along coastal areas. This usually occurs during passing tropical systems and nor'easters. The high winds produced by these events can pile water on the shorelines. If this occurs at the time of the astronomical high tide, the flooding is amplified and will inundate low-lying areas along the shorelines.

Urban Flooding
Urban flooding occurs in heavily developed areas where impervious surfaces do not allow water to be absorbed into the ground, thereby increasing the amount of water runoff. If areas are without proper drainage, or storm drains become clogged, then streets become streams and water will gather in low-lying areas. If it rains hard enough, underpasses can rapidly fill, trapping

motorists. Streets can accumulate enough water to submerge cars or carry them wherever the water flows.

Flash Flooding

Flash floods occur in a short period of time, or in a "flash". Rain falls at such a high rate that water does not have time to soak into the ground. Runoff flows downhill into ditches, lowlands and small streams. As the heavy rain continues, ditches overflow, drains backup, water ponds in lowlands, and streams rise over their banks. Streams and creeks can become raging rivers in just minutes. People are often caught off guard, especially motorists. Half of flash flood deaths in the United States are in automobiles.

River Flooding

River floods occur when heavy rains fall over a large area. In many cases in Virginia, it begins as widespread flash flooding of small streams. About 60 percent of Virginia's river floods begin with flash flooding from tropical systems passing over or near the state. River flooding also occurs as a result of successive rainstorms. Rainfall from any one storm is generally not enough to cause a problem, but with each successive storm's passage over the basin, the river rises until eventually it overflows its banks. If it is late winter or spring, melting snow in the mountains can produce added runoff that can compound flood problems.

Frequent flash flooding and urban flooding on the Peninsula is often caused by powerful thunderstorms that can dump one to four inches of rain in a few hours. Small creeks and streams as well as over-burdened drainage systems often cannot cope with the rapid influx of rain waters, especially when runoff is increased through urbanization of the watershed, or poor infiltration of precipitation due to overly wet or dry soils. The banks of non-tidal streams may quickly overtop, resulting in flooded roads and intersections and occasional property damage. The topography of much of the Peninsula is relatively flat and low-lying, which further hinders effective disbursement of runoff. Additional discussion regarding urban flooding and specific problem areas is included in Section 5 through detailed descriptions for each community.

4.1.3 Hurricanes and Tropical Storms

A hurricane is a type of low-pressure system, which generally forms in the tropics; similarly, a tropical storm is a low-pressure system of less intensity than a hurricane. Tropical systems are an important part of the atmospheric circulation system, distributing heat from the equatorial region to the higher latitudes. Hurricane season in the North Atlantic generally runs from June 1st until November 30th, with the peak season between August 15th and October 15th. Winds of a hurricane blow in a large, counter-clockwise spiral around a relatively calm center of extremely low pressure known as the eye. Around the rim of the eye, winds are most intense and may gust to more than 200 mph in a very strong storm.

Once a hurricane has formed, they maintain themselves by extracting heat energy from the ocean at high temperatures and releasing heat at the low temperatures of the upper troposphere. Hurricanes and tropical storms are violent systems that bring heavy rainfall, storm surge, high winds and may spawn tornados, all of which can cause significant damage. These storms can last for several days; however, the average hurricane duration is 12 to 18 hours. The duration and vast area impacted create the potential for sustained flooding, high wind, and erosion conditions across several states. While wind speeds can be expected to reduce by 50 percent within 12 hours of landfall, these storms are capable of producing a large amount of rain in a short period over a wide area.

Residents and emergency managers on the Peninsula are particularly interested in the track of any approaching storm. Proximity, direction, and strength are important factors when determining response measures, evacuation needs, and potential damage from the storm. When hurricanes approach land, forecasters often describe them as having four distinct quadrants: right-front, right-rear, left-front, and left-rear. The quadrants are relative to the hurricane's overall direction of motion and are significant in evaluating damage potential. The right-front quadrant generally causes the most destruction at the coast because the winds have an additive effect of sustained on-shore winds plus the motion of the hurricane. Onshore winds are strongest in the right-front quadrant; therefore, the surge and waves in that section are also the highest.

In 1971, wind engineer Herbert Saffir and hurricane expert Dr. Robert Simpson developed a scale to classify hurricanes. The Saffir-Simpson scale rates the intensity of hurricanes based on wind speed and barometric pressure measurements. The National Weather Service uses the scale to predict potential property damage and flooding levels from imminent storms. Although the scale assigns a wind speed and surge level to each category of storm, in recent years, there has been more and more recognition of the fact that wind speed, storm surge and inland rainfall are not necessarily of the same intensity for a given storm. Therefore, there is some interest in classifying hurricanes by separate scales according to each of these risks. However, the Saffir-Simpson Scale is still the most widely used classification tool for hurricanes. The scale is outlined in Table 4.1.3. Over time, researchers and meteorologists have further refined the analysis of the wind damage that hurricanes can produce by differentiating the concept of sustained winds from peak gusts. Sustained winds are measured over longer periods of time, typically a minute. A peak gust is the highest 2 to 5 second wind speed.

Table 4.1.3-Saffir-Sampson Scale

Category	Sustained Wind Speeds (mph)	Tidal Surge (ft)	Pressure (mb)	Typical Damage
Tropical Depression	<39	--	--	
Tropical Storm	39-73	--	--	
Hurricane Category 1	74-95	4-5	> 980	*Minimal* – Damage is done primarily to shrubbery and trees, unanchored manufactured homes are damaged, some signs are damaged, no real damage is done to structures on permanent foundations.
Hurricane Category 2	96-110	6-8	965-980	*Moderate* – Some trees are toppled, some roof coverings are damaged, major damage is done to manufactured homes.
Hurricane Category 3	111-130	9-12	945-965	*Extensive Damage* – Large trees are toppled, some structural damage is done to roofs, manufactured homes are destroyed, and structural damage is done to small homes and utility buildings.
Hurricane Category 4	131-155	13-18	920-945	*Extreme Damage* – Extensive damage is done to roofs, windows, and doors, roof systems on small buildings completely fail, some curtain walls fail.
Hurricane Category 5	> 155	> 18	< 920	*Catastrophic Damage* – Roof damage is considerable and widespread, window and door damage is severe, there are extensive glass failures, some buildings fail completely.

Storm Surge

The communities involved in this planning effort are particularly exposed to the high winds and storm surge associated with hurricanes due to the coastal topography and the large bodies of water surrounding the Peninsula. The greatest potential for loss of life related to a hurricane is from the storm surge. Storm surge is simply water that is pushed toward the shore by the force of the winds swirling around the storm. This advancing surge combines with the normal tides to create the hurricane storm tide, which can increase the mean water level 15 feet or more. In addition, wind waves are superimposed on the storm tide. This rise in water level can cause severe flooding on the Peninsula, particularly when the storm tide coincides with the normal high tides.

Surge maps for York County, the City of Hampton and Newport News are included in Appendix F. Surge maps for James City County are under development by United States Army Corps of Engineers (USACE). The City of Williamsburg is not considered susceptible to storm surge flooding. A surge map can provide a great deal of information if the reader understands how the maps were prepared and their intended use.

Surge maps are based upon a Sea, Lake and Overland Surges from Hurricanes (SLOSH) model and are the basis for the "hazard analysis" portion of the area's hurricane evacuation plans. SLOSH is a computerized model run by the National Hurricane Center (NHC) to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes by taking into account: pressure, size, forward speed, track, and winds.

Hundreds of hypothetical hurricanes are simulated with various Saffir-Simpson categories, forward speeds, landfall directions, and landfall locations. An envelope of high water containing the maximum value a grid cell attains is generated at the end of each model run. These envelopes are combined by the NHC into various composites which depict the possible flooding. One useful composite is the MEOW (Maximum Envelopes of Water) which incorporates all the envelopes for a particular category, speed, and landfall direction. Another composite that is useful to emergency managers is the MOM (Maximum of the MEOWs), which combines all the MEOWs of a particular category.

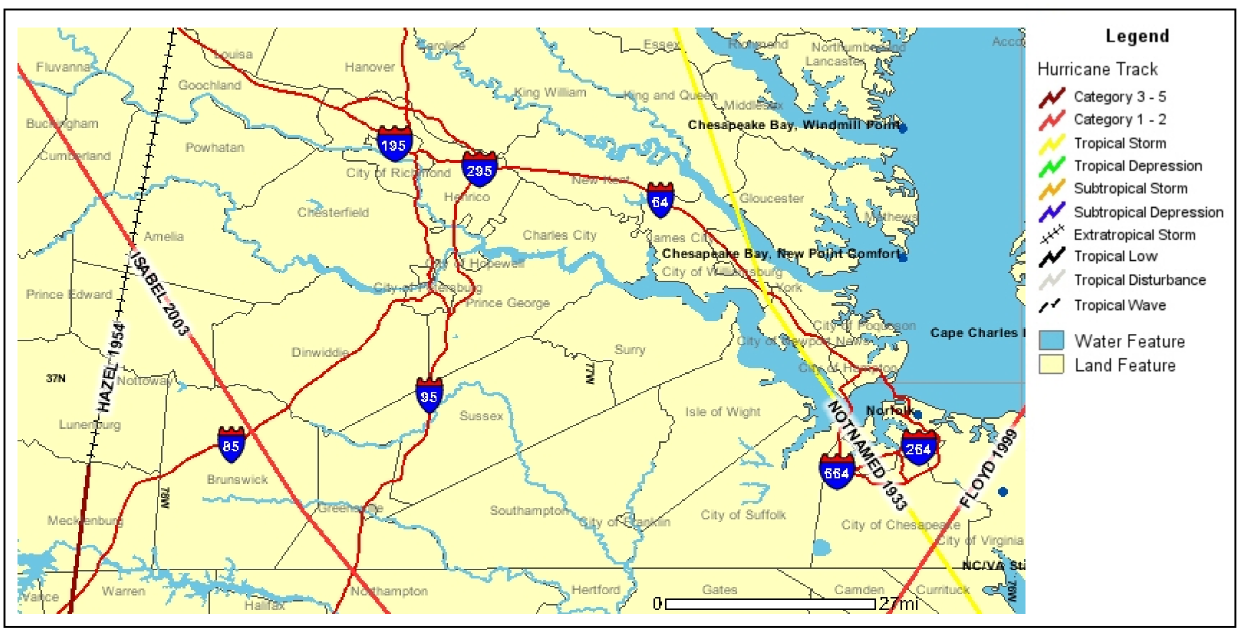
To provide some tools to emergency managers, regional evacuation studies have been completed using the SLOSH models. The MEOW maps are produced for all five levels of hurricane intensity and for many directions of storm motion, and they depict the "worse case" scenario for all categories of storms and all potential storm tracks. MEOW maps are just one tool an emergency manager will use to determine risk areas and evacuation recommendations.

The MOM (Maximum of MEOWs) storm surge maps for the Peninsula depict the "worst of the worst", and not the results of any one storm. There are no surge heights for Category Five storms because the region is generally not conducive to storms of that intensity.

History of Tropical Systems

Since 1851, 34 tropical systems have passed within 25 nautical miles of the Peninsula (see Appendix B). The Hurricane Maps and tables provided in Appendix B provide tracks and meteorological data for each of these systems. Additionally, Appendix C provides a more comprehensive set of information on individual storm events and the impacts to the Virginia coastal region as a whole. Data were obtained from a variety of sources as referenced in Appendix C. Community-specific damage information for hurricanes is provided in Section 5.

Figure 4.1.3 -Significant Tropical Storm Systems, Virginia Peninsula



Source: NOAA CSC Hurricane Mapping Tool

Figure 4.1.3 indicates the paths of particularly noteworthy tropical systems for Peninsula communities, except the 1749 storm described below. The list of noteworthy storms includes:

- **October 19, 1749,** a tremendous hurricane created Willoughby Spit, south of Hampton. The Bay rose 15 feet above normal. In Williamsburg, a family drowned as flood waters carried their house away. At Hampton, water rose to four feet deep in the streets; many trees were uprooted or snapped in two. Bodies washed ashore from shipwrecks for days afterward. Hurricane wiped out Ft. Monroe's predecessor, Ft. George.

- **Chesapeake-Potomac Hurricane, August 23, 1933,** established record high tides in many locations; approximately 9.8 feet above mean lower low water. There were four casualties on the Peninsula: two in Hampton, one in James City County, and one in York County. At Buckroe Beach in Hampton, and at Yorktown, marshal law was declared and National Guard troops were brought in to prevent looting. Flooding was severe in low-lying parts of Hampton (Fox Hill and Buckroe), York County (Goodwin Neck), and Newport News (Small Boat Basin). Jamestown Island was severely damaged.

- **Hurricane Hazel, October 15, 1954,** inflicted 130mph winds on Hampton and blew apart at least one anemometer there. There was one casualty on the Peninsula in the Dare section of York County.

- **Hurricane Floyd, September 6, 1999,** passed directly over Virginia Beach as a Category 1 Hurricane. Rainfall amounts in areas west of the Peninsula reached staggering amounts in excess of 15 inches. Prior rainfall created wet conditions that led to flooding in some parts of Newport News and Hampton.

- **Hurricane Isabel, September 18, 2003**, made landfall near Ocracoke, North Carolina as a Category 2 hurricane, and the center passed west of Emporia. Isabel brought hurricane conditions to the Peninsula and caused significant flooding, with highest tide at Sewells Point of 7.9 feet above mean lower low water, a 5 foot storm surge. There was significant beach and shore erosion along much of the Peninsula's shoreline. Grandview and Buckroe areas of Hampton, Newport News/James River waterfront, Seaford area of York County and Yorktown waterfront had many structures severely damaged by storm surge. On the Peninsula, Isabel indirectly caused one drowning death in Newport News and one debris cleanup accident fatality in York County. Statewide, the storm resulted in $1.6 billion in damages with over 1,186 homes and 77 businesses completely destroyed, 9,110 homes and 333 businesses with major damage, and over 107,000 homes and 1,000 businesses with minor damage. Hundreds of power lines were blown down leaving almost two million electrical customers without power. Crop losses were calculated to be $59.3 million with another $57.6 million in damages to farming infrastructure.

4.1.4 Tornados

Tornados are one of nature's most violent storms. A tornado is a violent windstorm characterized by a twisting, funnel-shaped cloud, circulating in a counterclockwise direction.

Tornados are spawned by a thunderstorm (sometimes as part of a hurricane) and produced when cool air overrides a layer of warm air, forcing the warm air to rise rapidly. The damage from a tornado is a result of the high wind velocity and wind-blown debris. Tornado season is generally March through August, although tornados can occur at any time of year. They tend to occur in the afternoons and evenings; over 80 percent of all tornados strike between noon and midnight. Tornados generally travel along squall lines, in a direction from southwest to northeast.

In an average year, about 1,000 tornados are reported across the United States, resulting in 80 deaths and over 1,500 injuries. The most violent tornados are capable of tremendous destruction with wind speeds of 250 mph or more. Damage paths can be in excess of one mile wide and 50 miles long. A tornado's destructive power is measured using the Fujita Damage Scale (See Table 4.1.4a). A tornado's intense power often destroys homes, downs power lines, and can cause significant tree damage.

Table 4.1.4a -Fujita Damage scale

Scale	Wind Estimate (mph)	Typical Damage
F0	< 73	Light Damage Some damage to chimneys; branches off trees; shallow-rooted trees pushed over; sign boards damaged.
F1	73-112	Moderate Damage. Peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos blown off roads.
F2	113-157	Considerable Damage. Roofs torn off frame houses; mobile homes demolished; boxcars overturned; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
F3	158-206	Severe Damage. Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forest uprooted; heavy cars lifted off the ground and thrown.
F4	207-260	Devastating Damage. Well-constructed houses leveled; structures with weak foundations blown away some distance; cars thrown and large missiles generated.
F5	261-318 mph	Strong frame houses lifted off foundations and carried considerable distances to disintegrate; automobile sized missiles fly through the air in excess of 100 meters; trees debarked; steel re-enforced concrete structures badly damaged.
F6	319-379 mph	These winds are very unlikely. The small area of damage they might produce would probably not be recognizable along with the mess produced by F4 and F5 wind that would surround the F6 winds. Missiles, such as cars and refrigerators would do serious secondary damage that could not be directly identified as F6 damage. If this level is ever achieved, evidence for it might only be found in some manner of ground swirl pattern, for it may never be identifiable through engineering studies

Source: Fujita, 1971.

Most tornados on the Peninsula have occurred from June through October, and the magnitudes range from F0 to F3. The most significant tornado to strike the Peninsula in recent history was an F3 tornado in Newport News on September 5, 1979. The tornado cut a path 50 yards wide and 3 miles in length, and caused an estimated \$2.5 million in property damage. In addition to tornados over land, Peninsula residents are also subject to more common waterspouts, or tornados over water. The interaction of cool coastal breezes and warm air masses over land create ideal tornado conditions when thunderstorms move over this boundary (Watson 2004c).

The tornado history compiled for Table 4.1.4b provides information on Peninsula tornados that caused significant damage, and was compiled from the NCDC database and Watson (2004b). The list begins with a storm in 1951. Quite obviously, tornados occurred on the Peninsula before 1951, but records of these storms were not readily available for the purposes of this plan. As with lighting strikes, if there is no sighting or confirmation of a tornado, inclusion in the body of tornado statistics is not likely, so this table should not be considered an all-inclusive list of tornados impacting the Peninsula.

Table 4.1.4b -Significant Historical Tornados Impacting the Peninsula

Community	Date	Magnitude	Deaths	Injuries	Property Damage	Crop Damage	Associated Tropical Cyclone?
Newport News	June 27, 1951	F1	0	0	$3K	0	No
York County	November 1, 1951	F1	0	0	$3K	0	No
Newport News	April 6, 1958	F1	0	0	$250K	0	No
Newport News	October 7, 1965	F0	0	0	$3K	0	No
Newport News	September 5, 1979	F3	0	2	$2.5M	0	Yes, David
Hampton	September 5, 1979	F2	0	9	$250K	0	Yes, David
Newport News	June 1, 1982	F0	0	0	$0K	0	No
Hampton & Newport News	August 6, 1993	F1	0	10	$5.0M	0	No
York County	July 12, 1996	F1	0	0	$15K	0	Yes, Bertha
Hampton	September 4, 1996	F0	0	0	$1K	0	Yes, Fran
Hampton	September 4, 1999	F2	0	6	$7.7M	0	Yes, Dennis
Newport News	August 11, 2001	F0	0	0	$50K	0	No
York County	August 7, 2003	F1	0	0	$20K	0	No
Hampton	August 30, 2004	Not reported	0	0	Not reported	0	Yes, Gaston

Sources: NCDC and Watson 2004b.

Appendix B contains map output from the NWS software SVRPLOT of tornado occurrences in the Tidewater region between 1950 and 2002.

4.1.5 Nor'easters

Nor'easters are coastal storms that develop off the mid-Atlantic Coast during late fall, winter and early spring. The storms are named after the direction of the prevailing winds. The storms may rapidly and unexpectedly intensify, gaining strength from the relatively warm air over the Atlantic Ocean. Simultaneously, colder air is forced southward along the East Coast. This mixture of warm and cold air can produce rain, snow, sleet, or freezing rain. The coastal plain of Virginia typically receives rain if the storm tracks over the coast or inland east of the Appalachian Mountains. When a storm center tracks east over the Atlantic Ocean, the Peninsula can receive record snowfalls.

Nor'easters generate strong northeast winds, heavy precipitation and storm surge on the Peninsula. Although the winds and storm surge associated with nor'easters are generally less intense than that of hurricanes, nor'easters can linger for several days over a given area. Storms with a long duration allow large accumulations of precipitation and damage to structures that are exposed to high wind and flooding. High-pressure systems to the north can hinder movement of the lows and serve to increase the severity of the low, thereby increasing the impacts of the storm.

The Dolan-Davis Scale (1993), Table 4.1.5a, was developed to identify and classify the damages that may occur during nor'easters. Although rarely referenced by the National Weather Service or other media in describing nor'easters (Sammler, 2005), the scale provides a useful descriptive tool for the types and levels of damage associated with a nor'easter. Heavy precipitation in the form of rain or snow, beach and dune erosion from wave action, sand/water overwash associated with storm surge, and resultant coastal property damage are all commonly associated with strong nor'easters.

Table 4.1.5a - Dolan-Davis Nor'easter Intensity Scale

Storm Class	Beach Erosion	Dune Erosion	Overwash	Property Damage
1 (Weak)	Minor changes	None	No	No
2 (Moderate)	Modest; mostly to lower beach	Minor	No	Modest
3 (Significant)	Erosion extends across beach	Can be significant	No	Loss of many structures at local level
4 (Severe)	Severe beach erosion and recession	Severe dune erosion or destruction	On low beaches	Loss of structures at community-scale
5 (Extreme)	Extreme beach erosion	Dunes destroyed over extensive areas	Massive in sheets and channels	Extensive at regional-scale; millions of dollars

Source: Davis and Dolan, 1993

Erosion

The exposed coastline of the Peninsula is subject to severe erosion during nor'easters and winter storms. Mechanical, chemical, and biological agents contribute to the wearing away or removal of coastal lands, resulting in a landward retreat of the shore. High waves and strong currents initiate coastal erosion, while breaking waves contribute to the process by suspending sediment particles and dislodging rocks. When the forces causing erosion occur at high tide, and especially during spring high tide, the resultant flooding and overwash can significantly increase the land loss and property damage. (Morton, 2003) The erosion of unconsolidated sediments and tidal wetlands throughout the Peninsula is a recurring hazard; however, private property losses and shoreline erosion are rarely quantified. The Virginia Institute of Marine Science continues to research the hazard, and maintains much data for the Gloucester Point area north of the Peninsula.

Tropical systems, nor'easters, and winter storms generate breaking waves and strong currents that have the effect of contributing new sediment to the littoral system and redistribute pre-existing sediments over large areas of the shoreface. A variety of factors, including beach composition and storm characteristics, determine how beaches are affected by storms. For example, retreat of bluffs and muddy shores occurs in an episodic, stepwise pattern without any seaward advancement between retreat events, as has historically occurred along the York River near Yorktown. Sandy beaches, like Buckroe Beach and Grandview in Hampton, tend to partially recover after storms. (Morton, 2003)

Historical Nor'easters

Almost every year, in late fall, winter or spring, the Peninsula is impacted by one or more nor'easters of varying degrees of severity. Table 4.1.5b provides a listing of historic nor'easters that have inflicted damage along the Virginia coastline, including the Peninsula. Due to the high frequency of these storms, communities on the Peninsula do not maintain detailed cost accounting for individual storms and the associated damage.

Table 4.1.5b - Historic Virginia Nor'easters

Date	Description
January 18-19, 1857	More than a foot of snow fell with temperatures in the single digits and teens across the state. Strong winds caused structural damage on land and wrecked ships at sea. One account states that Norfolk was buried under 20 foot drifts of snow. Temperatures fell to between -10° to -17° in the city. According to eyewitness accounts, the cold was so extreme that all Virginia rivers were frozen over. The Chesapeake Bay was solid ice a mile and a half out from its coast. At Cape Henry, one could walk out 100 yards from the lighthouse on the frozen ocean.
March 1-2, 1872	Known as the "Great Storm of 1872." During the evening of March 1, winds increased from the northeast to gale force (over 40 mph) on the coast and snow began blowing and drifting. It was very cold and the snow accumulated several inches. The wind drove water up into the Tidewater area and up the rivers. Water rose rapidly flooding wharves and the lower part of Norfolk.
April 11, 1956	Tidewater experienced gale winds (40 mph +) and unusually high tides. At Norfolk, the strongest gust was 70 mph. The strong northeast winds blew for almost 30 hours and pushed up the tide which reached 4.6 feet above normal in Hampton Roads. Thousands of homes were flooded by the wind-driven high water and damages were high. Two ships were driven aground. Waterfront fires were fanned by the high winds and, the flooded streets made access for firefighters very difficult, adding to the damages.
March 6,1962 Ash Wednesday Storm	The storm hit Virginia during spring tide, when sun and moon phase to produce a higher than normal tide. Storm moved north off the coast past Virginia Beach and then reversed its course moving again to the south and bringing with it higher tides and higher waves which battered the coast for several days. The storm's center was 500 miles off the Virginia Capes when water reached nine feet at Norfolk and seven feet on the coast. Huge waves toppled houses into the ocean and broke through Virginia Beach's concrete boardwalk and seawall. Houses on the Bay side also saw extensive tidal flooding and wave damage. An estimated $4 million in wind and flood damages occurred in Hampton. Winds up to 70 mph built 40-foot waves at sea. Flooding had a devastating effect on the Peninsula, including Grandview (Hampton) and Poquoson. Legendary storm caused over $200M (1962 dollars) damage from North Carolina to Long Island, New York.
January 27, 1998	Slow-moving nor'easter combined with high tides resulted in an extended period of gale force onshore winds, driving tides to 6.44 feet above MLLW at Sewells Point. Moderate coastal flooding was reported across the middle Peninsula and Northern Neck areas. The damage was estimated at $1.5 million.

Date	Description
March 13-14, 1993	The "Superstorm of March '93" was also known as "The Storm of the Century" for the eastern United States, due to its large area of impact, all the way from Florida and Alabama through New England. As the storm's center crossed Virginia, weather stations recorded their lowest pressure ever. Unlike most big winter storms that move up the coast, this storm took a more inland track across Richmond and the Chesapeake Bay. It brought rain and some high winds to Southeast Virginia and heavy snow and blizzard conditions over portions of the north and west. Eleven people died in Virginia from over-exertion and heart attacks shoveling snow or from exposure and hypothermia. Snow removal and clean-up costs were estimated at 16 million dollars statewide.
February 4,1998	Storm battered eastern Virginia for 3 days. Storm's slow movement resulted in an extended period of gale and storm force onshore winds, driving tides to 7.0 feet above MLLW at Sewell's Point in Norfolk. High tides resulted in severe coastal flooding throughout Hampton Roads and Eastern Shore. Damage was estimated at $75 million for Hampton Roads. $314,000 in costs incurred by York County government; approximately $75% direct damage, %20 debris-related, and 5% emergency response costs.
January 24-25, 2000	Storm spread heavy snow into Virginia. Several inches of snow was on the ground at daybreak on the 25th, with winds gusting at 25 to 45 mph, creating blizzard conditions in some areas. The region was at a standstill; airports and transit systems were shut down, schools were closed, Federal, state and county government offices were closed. Drifts of four to five feet were common. Snow mixed with sleet and freezing rain in some of the eastern counties of Virginia.

Source: VDEM 2004

4.1.6 Thunderstorms

Virginia averages 40 to 50 thunderstorm days per year (Sammler, 2005). Thunderstorms can occur any day of the year and at any time of the day, but are most common in the late afternoon and evening during the summer months, and in conjunction with frontal boundaries. Thunderstorms are generally beneficial because they provide needed rain for crops, plants, and reservoirs. About five percent of thunderstorms become severe and can produce tornados, large hail, damaging downburst winds, and heavy rains causing flash flooding. Thunderstorms can develop in less than 30 minutes, allowing little time for warning. The National Weather Service does not issue warnings for ordinary thunderstorms nor for lightning. The National Weather Service highlights the potential for thunderstorms in the daily forecasts and statements. Thunderstorms often create hazardous boating conditions for Peninsula mariners, who must be diligent in monitoring weather broadcasts for advance notice of late afternoon squalls or squall lines.

All thunderstorms produce lightning, which can be deadly. A bolt of lightning can strike 10 to 15 miles from the rain portion of a thunderstorm. The lightning bolt originates from the upper part of the thunderstorm cloud known as the anvil. A thunderstorm can grow up to 8 miles into the atmosphere where the strong winds aloft spread the top of the thunderstorm cloud out into an anvil. The anvil can spread many miles from the rain portion of the storm but it is still a part of that storm. Lightning bolts may come from the front, side or back of the storm, even striking after the rain and storm seem to have passed, or striking areas missed by rain.

Between 1959 and 2000, lightning killed 58 people in Virginia and injured at least 238 (Watson 2004). On the Peninsula, there have been at least 13 noteworthy lightning strikes since 1993, as shown in Table 4.1.6. The majority of the damage caused by lightning in the area was related to home strikes, and power line failures, but one person was reported injured and one person was reported killed. A typical 100-million volt lightning flash can heat the air to more than 40,000 degrees in an instant. This amazing amount of power can damage homes, down trees and power lines, and take lives. The best defense against this natural hazard is to recognize the danger and take shelter when appropriate.

Table 4.1.6- Recent Lightning Damage for Peninsula Communities*

Location	Date	Type	Death	Injury	Property Damage
Hampton	07/16/2003	Lightning	0	0	5K
Newport News	06/20/1996	Lightning	0	0	0
Newport News	06/19/2000	Lightning	0	0	100K
Newport News	06/06/2001	Lightning	0	0	0
Williamsburg	01/02/1996	Lightning	0	0	20K
Williamsburg	07/17/1995	Lightning	0	0	25K
Williamsburg	04/01/1993	Lightning	0	0	50K
Norfolk	09/04/1993	Lightning	0	1	500K
York County	06/26/2001	Lightning	0	0	0
Grafton	07/15/2000	Lightning	0	1	20K
Centerville	08/24/2000	Lightning	0	0	100K
Jamestown	08/30/2003	Lightning	1	0	0
James City County**	09/20/2005	Lightning	0	0	Roof damaged by fire, holes in roofs/walls

* Events shown were collected by NCDC and likely represent only a fraction of total lightning strikes.
***Daily Press*, 9/22/05

Figure 4.1.6 is based upon lightning strike data for the year 1989. The detector network established by the Electric Power Research Institute (EPRI) identified strikes, and the Virginia State Climatology Office compiled the map. Lightning data from EPRI are only available for a fee, and lightning data collected by NWS and NCDC do not detect all lightning strikes or occurrences. The figure below is only a one-year sample of the lightning climatology for the state; however, it depicts a distinct east-west geographic pattern of lightning strikes in 1989, with the Peninsula experiencing four to five flashes per square kilometer overall.

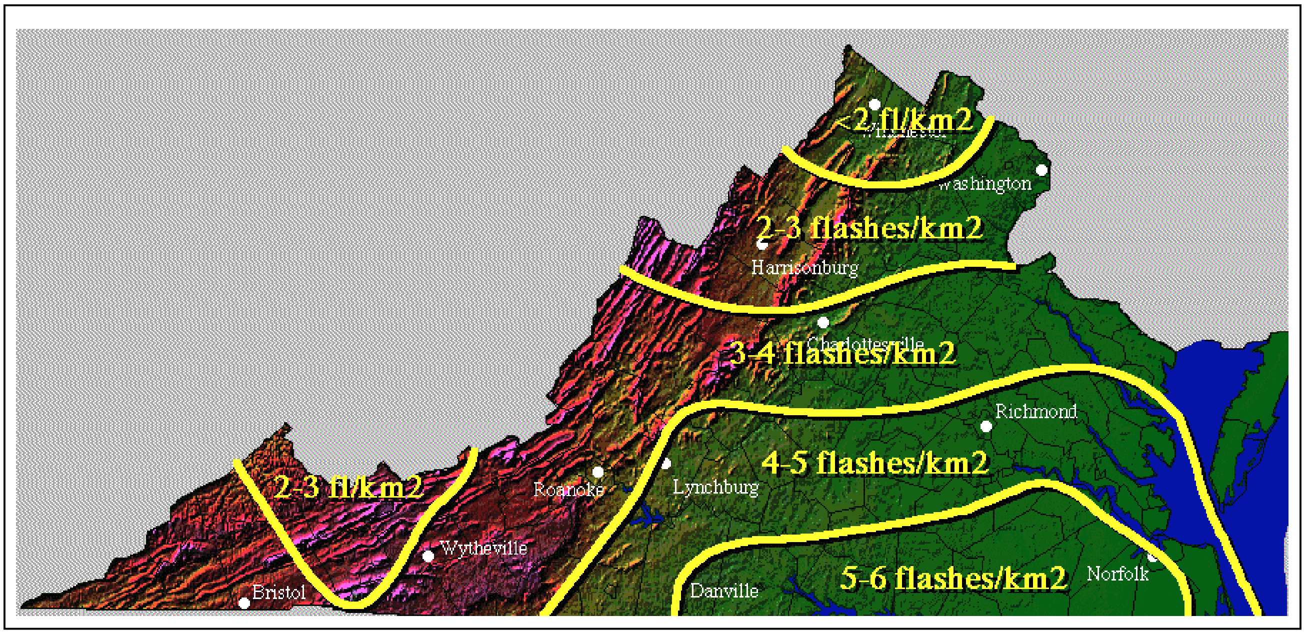
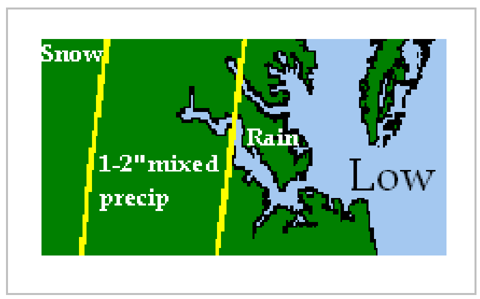


Figure 4.1.6 Virginia Lightning Strike Density Map for 1989 Only(State Climatology Office)

4.1.7 Winter Storms

Figure 4.1.7- Winter Storm Precipitation Pattern for the Peninsula



Source: VDEM 2004

Winter storms can refer to various types of precipitation including snow, freezing rain and ice. Sometimes winter storms are accompanied by strong winds creating blizzard conditions with blinding wind-driven snow, severe drifting, and dangerous wind chill. Strong winds with these intense storms and cold fronts can knock down trees, utility poles, and power lines. Heavy accumulations of ice can bring down trees, electrical wires, telephone poles and lines, and communication towers. Communications and power can be disrupted for days while utility companies work to repair the potentially extensive damage. Even small accumulations of ice may cause extreme hazards to motorists and pedestrians. Heavy snow can immobilize a region and paralyze a community, stranding commuters, stopping the flow of supplies, and disrupting emergency and medical services. Accumulations of snow can collapse buildings and knock down trees and power lines. In rural areas, homes and farms may be isolated for days, and unprotected livestock may be lost. The cost of snow removal, repairing damages, and loss of business can also have a significant economic impact on communities.

Although not all of Virginia's biggest winter storms are nor'easters, many of them are. At times, nor'easters have become so strong and produced such large amounts of blowing snow, that they have been termed "White Hurricanes."

Wind blowing counter clockwise around the storm center carries warm, moist air from the Gulf Stream up and over the cold inland air. The warm air rises and cools and snow begins. Heavy snow often falls in a narrow 50 mile wide swath about 150 miles northwest of the low pressure center (see Figure 4.1.7- Low pressure center or storm center is represented by "Low"). The Peninsula area is often affected by these storms.

It is also not uncommon for the Peninsula area to experience sleet, freezing rain, and ice storms. In fact, the Peninsula area has experienced 19 major winter weather events from 1993 – 2003. One such event occurred in December 1998. A major ice storm hit central and eastern Virginia, with ice accumulations of 0.5 – 1.0 inches that left dozens of power lines downed along with hundreds of tree limbs. Over 400,000 people in the area were left without power. The combination of automobile accidents, power line repair and clean-up cost the area over $20 million (NCDC 2004).

The recurrence of severe winter weather in the Peninsula area is certain. These winter storms often leave tree limbs and power lines down resulting in dangerous conditions. Other impacts can include collapsed roofs from fallen trees and heavy ice and snow loads as well as icy roads and sidewalks. Winter weather can have devastating effects on a community and occurs fairly frequently.

Table 4.1.7- Significant Winter Storm Events

Date	**Description**
January 18-19, 1857	See description in **Table 4.1.5b-Historic Virginia Nor'easters**
March 1-2, 1872	See description in **Table 4.1.5b-Historic Virginia Nor'easters**
November 17, 1873	Severe storm and gale brought high tides to tidewater area flooding wharves and the lower portion of Norfolk.
December 26-28, 1892	Norfolk set three local records for snow (Official Weather Records began in 1871). The greatest single storm amount with 18.6 inches; the most in 24 hours with 17.7 inches; and the maximum depth of snow on the ground with 18.6 inches. Normal snowfall at Norfolk is only 7.8 inches per year.
Winter of 1960-1961	Stormy pattern of previous winters continued with three more significant storms. The first was December 10-12, 1960 with heavy snow and high winds from Virginia to New York. In Virginia, snow fall ranged from 4 -13 inches in the north and west. Seven fatalities in Virginia. The next snowstorm struck on January 19-20 from North Carolina to New York. Virginia saw up to 12 inches. Two deaths were blamed on the storm in Virginia, due to overexertion and accidents. The third storm struck February 3-5 and hit like a blizzard with severe cold and gale force winds. Two to 13 inches of snow across Virginia, and four fatalities.
March 6, 1962 Ash Wednesday Storm	See description in **Table 4.1.5b-Historic Virginia Nor'easters**
Winter of 1980	On January 4 and 5, a heavy wet snow fell over eastern Virginia with as much as 18 inches reported at Williamsburg. A second storm hit on February 6 that dumped 6 inches in Williamsburg and as much as 20 inches at Virginia Beach. Over a foot of snow fell in Norfolk. Once again, arctic air had settled over Virginia and temperatures were in the teens. More than 1 foot of snow at Norfolk. The heavy snow combined with strong winds to create blizzard conditions. Norfolk's total for the season came to a

Date	Description
	record 41.9 inches making this the snowiest winter ever for eastern Virginia.
February 1989	This was a month of big swings in the weather for Southeast Virginia. Twice, Hampton Roads saw record high temperatures in the mid 70°s followed by a significant snowfall. The two storms that struck dumped a record 24.4 inches of snow at Norfolk. Over 14 inches occurred during one 24 hour period. It was the most snow to occur in one month in southeast Virginia in the last 100 years.
March 13-14, 1993	See description in **Table 4.1.5b-Historic Virginia Nor'easters**
January 6-8, 1996	Much of the eastern seaboard received 1 to 3 feet of snow. Wind gusts of over 50 mph were common and resulted in blizzard conditions for much of the east coast, including Virginia. Many areas of Virginia received over 20 inches of snow. Numerous accidents and flood related damages were reported in the area, along with 13 deaths in Virginia. Virginia, along with Ohio, Pennsylvania, Maryland, West Virginia and New York were declared Presidential Disaster Areas. All totaled the blizzard and resulting flooding killed and estimated 187 people and caused approximately $3 billion in damages along the eastern seaboard.
December 23, 1998	A prolonged period of freezing rain and some sleet resulted in ice accumulations of up to an inch. The heavy ice accumulations on trees and power lines caused widespread power outages. Many accidents occurred due to slippery road conditions, especially bridges and overpasses. Many secondary roads and parts of I-64 on the Peninsula were impassable due to fallen trees and tree limbs. Approximately 400,000 people were left without power in central and eastern Virginia and damages totaled more than $20 million. York County estimated at last $300,000 in damage costs incurred by the County; approximately 75% direct damage, 20% debris-related, and 5% emergency response costs.
February, 2004	On February 15 and 16, a winter storm hit the Tidewater area of Virginia dumping wind driven rain, freezing rain, and snow on a significant portion of Hampton Roads. Snow accumulation totals in some areas reached three to six inches and winds were reported at up to 30 mph. Sleet fell across much of the region causing roads to become icy and treacherous.

Source: NCDC

4.1.8 Extreme Heat

Extreme heat hazards result from high daily temperatures combined with high relative humidity. High relative humidity retards evaporation, robbing the body of its ability to cool itself. On average, about 175 Americans succumb to the taxing demands of heat every year (NOAA 2004).

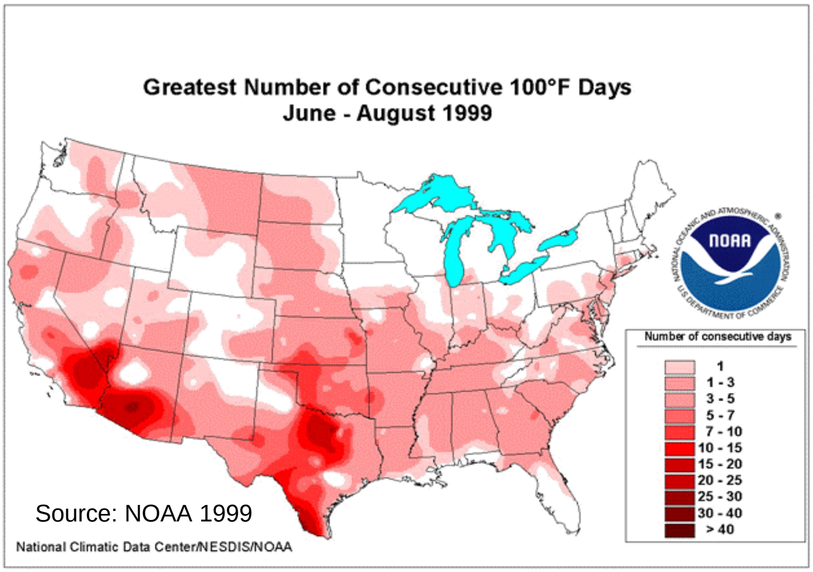
When heat gain exceeds the level the body can remove, body temperature begins to rise, and heat related illnesses and disorders may develop. The Heat Index (HI) is the temperature the body feels when heat and humidity are combined. Table 4.1.8 shows the HI that corresponds to the actual air temperature and relative humidity. This chart is based upon shady, light wind conditions. Exposure to direct sunlight can increase the HI by up to 15°F. (NOAA 2004).

Table 4.1.8 -Heat Index

Temperature (°F)	Relative Humidity					
	90%	80%	70%	60%	50%	40%
80	85	84	82	81	80	79
85	101	96	92	90	86	84
90	121	113	105	99	94	90
95		133	122	113	105	98
100			142	129	118	109
105				148	133	121
110						135

Source: NOAA 2004

Figure 4.1.8-Greatest Number of Consecutive 100°F Days



During the summer (June-August) of 1999, the United States experienced an intensifying drought and heat wave. The east coast was the area hardest hit by the drought, with record and near-record short-term precipitation deficits occurring on a local and regional scale resulting in agricultural losses and drought emergencies being declared in several states (NOAA 1999). Figure 4.1.8 shows the number of consecutive days of 100° temperatures.

The threat of extreme heat to the Peninsula communities is episodic and, although it cannot be controlled, threats to the population can be minimized by warnings and public awareness of the potential dangers that extreme heat presents.

4.1.9 Dam Failure

For the purposes of this plan, dam failure is addressed as a natural hazard resulting in a flooding condition. Dam failure can occur if hydrostatic pressure behind a dam exceeds design capacity or the crest of the dam is over-topped and rushing flood water scours the base of the dam. The hazard classification associated with dam failure is outlined below. Dams that meet regulatory criteria in Virginia are regulated under the Dam Safety Act established by the Virginia Soil and Water Conservation Board (VS&WCB). A dam may be exempt from the regulation if any of the following criteria apply:

- dam is less than 6 feet in height,
- dam has a capacity less than 50 acre-feet and is less than 25 feet in height,
- dam has a capacity of less than 15 acre-feet and is more than 25 feet in height,
- dam is used for primarily agricultural purposes and has a capacity less than 100 acre-feet (should use or ownership change, the dam may be subject to regulation),
- dam is owned or licensed by the Federal Government, or
- dam is operated for mining purposes under 45.1-222 or 45.1-225.1 of the *Code of Virginia*.

Dams are assigned a hazard classification based on the downstream loss anticipated in the event of dam failure. Hazard potential is not related to the structural integrity of the dam. The hazard potential classification speaks to the level of risk to life and economic loss the dam imposes on downstream properties and facilities. The classification scheme used by VS&WCB is as follows:

- **Class I** - dams which upon failure would cause probable loss of life or excessive economic loss,
- **Class II** - dams which upon failure could cause possible loss of life or appreciable economic loss,
- **Class III** - dams which upon failure would not likely lead to loss of life or significant economic loss, and
- **Class IV** - dams which upon failure would not likely lead to loss of life or economic loss.

The owner of each regulated Class I, II, or III dam is required to apply for an operational and maintenance certificate from VS&WCB. One of the requirements for obtaining the operational and maintenance certificate is the development of an emergency action plan. These plans are filed with the local emergency management official and VDEM. Table 4.1.9 provides the number of dams by classification for each community on the Peninsula. For further information regarding specific dams, please contact the local emergency management department.

Community	High Hazard		Low Hazard	
	Class I	Class II	Class III	Class IV
Hampton	0	0	0	0
Newport News	0	2	0	0
Williamsburg	0	1	1	1
James City County	0	0	1	0
York County	0	1	1	0

Table 4.1.9 - Number of Dams by Community and Hazard Classification

4.1.10 Wildfire

A wildfire is an uncontrolled fire spreading through vegetative fuels, exposing and possibly consuming structures. Wildfires often start unnoticed and spread quickly, causing dense smoke that fills the area for miles around. Naturally occurring and non-native species of grasses, brush, and trees fuel wildfires. (FEMA, How-to Guide, 2-29) Generally, there are three major factors to consider in assessing the threat of wildfires to a community: topography, vegetation, and weather.

The type of land cover in an area affects a number of factors including ease of ignition, the intensity with which a fire burns, and the facilitation of wildfire advancement. Topographic variations, such as steep slopes, can lead to a greater chance of wildfire ignition. Generally, steep slopes are predisposed to convective pre-heating, which warms and dries the vegetative cover. Also, slopes that face south receive more direct sunlight than those facing north. Direct sunlight dries vegetative fuels, creating conditions that are more conducive to wildfire ignition. Population density has a causal relationship to wildfires because humans ignite an overwhelming majority of the wildfires in Virginia, intentionally or unintentionally. Travel corridors increase the probability of human presence, which increases the potential for wildfire ignition. Hence, areas close to roads have a higher ignition probability. Storms such as hurricanes and winter ice storms can topple trees, creating an enormous amount of debris, which can serve as wildfire fuel.

Recently, Hurricane Isabel brought down thousands of trees on the Peninsula. The resultant increase in potential fuel initiated a public awareness campaign by VDOF to educate the public regarding the increased hazard.

According to VDOF, approximately 30 percent of the Peninsula land area is a high fire risk zone, 38 percent is a moderate fire risk zone, and 32 percent is a low fire risk zone. See Appendix B for a map showing the boundaries of the wildfire hazard areas for all Peninsula communities. Table 4.1.10 summarizes the percentage of land area exposed to wildfire hazard for each Peninsula community. VDOF reports that there were approximately 32 wildfires on the Peninsula between 1995 and 2001, which resulted in approximately 70 acres of burned land (VDOF 2003).

Table 4.1.10 -Wildfire Hazard for Peninsula Communities

Community	Land Area (sq. mi.)	Fire Risk (sq. mi.)		
		High	Medium	Low
Hampton	51.8	3.5 (6.7%)	6.0 (11.6%)	42.3 (81.7%)
Newport News	176.9	16.1 (9.1%)	36.8 (20.8%)	124.0 (70.1%)
Williamsburg	8.5	0.8 (9.0%)	3.1 (36.1%)	4.7 (54.9%)
James City County	143.0	47.6 (33.3%)	18.0 (12.6%)	77.4 (54.1%)
York County	106.0	53.0 (50.0%)	42.3 (39.9%)	10.7 (10.1%)
Total	486.2	147.8 (30.4%)	183.8 (37.8%)	154.1 (31.7%)

4.1.11 Drought

All of the Peninsula communities are susceptible to droughts, which are defined by a combination of intensity and duration. In a one-year time frame, droughts are considered large when the 12-month rainfall averages about 60 percent of normal. On a multi-year time scale, 75 percent of normal rainfall indicates a serious problem. High summer temperatures can exacerbate the severity of a drought. Normal high summer temperatures in central and eastern Virginia can reach the 90 degree mark and higher. Most of the soil is relatively wet, and a great deal of the sun's energy goes toward evaporation of the ground moisture. However, when drought conditions eliminate soil moisture, the sun's energy goes toward heating the ground surface and temperatures reach into the low 100's – further drying the soil. This can have a devastating effect on crops, stream levels and water reserves. A short-term precipitation deficit of six summer weeks can often ruin crops. Droughts lasting a year, which occur in the Mid-Atlantic when the region receives 60 percent of the typical 40 inches of rain, begin to draw down water wells and livestock ponds and decrease stream flows and water reserves.

VDEM rates Virginia's drought risk as "Significant," with Virginia communities experiencing approximately 20 years of severe drought in the last century. These droughts have caused millions of dollars of damage. There are two primary drought monitoring tools currently in use in the United States. The Palmer Drought Index (PDI) has been used for U.S. drought monitoring for the last 30 years. It is based on a water budget model that incorporates the balance between water supply (i.e., precipitation), soil moisture, runoff, and water demand (computed from estimates for evaporation and transpiration). The U.S. Drought Monitor is a blend of science and subjectivity, resulting in a drought severity classification table based on ranges for primary indicators for each dryness level. Because the ranges of the various indicators often do not coincide, the final drought category tends to be based on what the majority of the indicators show. The analysts producing the map also weight the indices according to how well they perform in various parts of the country and at different times of the year. The PDI is one of many indicators used to develop the U.S. Drought Monitor. Other indicators include: soil moisture, weekly streamflow, standardized precipitation, and a satellite vegetation health index. Table 4.1.11 provides a description of possible impacts for the drought severity categories indicated by the U.S. Drought Monitor.

Table 4.1.11 -U.S. Drought Monitor, Drought Severity Classification

Category	Description	Possible Impacts
D0	Abnormally Dry	Going into drought: short-term dryness slowing planting, growth of crops or pastures; fire risk above average. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered.
D1	Moderate Drought	Some damage to crops, pastures; fire risk high; streams, reservoirs, or wells low, some water shortages developing or imminent, voluntary water use restrictions requested
D2	Severe Drought	Crop or pasture losses likely; fire risk very high; water shortages common; water restrictions imposed
D3	Extreme Drought	Major crop/pasture losses; extreme fire danger; widespread water shortages or restrictions
D4	Exceptional Drought	Exceptional and widespread crop/pasture losses; exceptional fire risk; shortages of water in reservoirs, streams, and wells, creating water emergencies

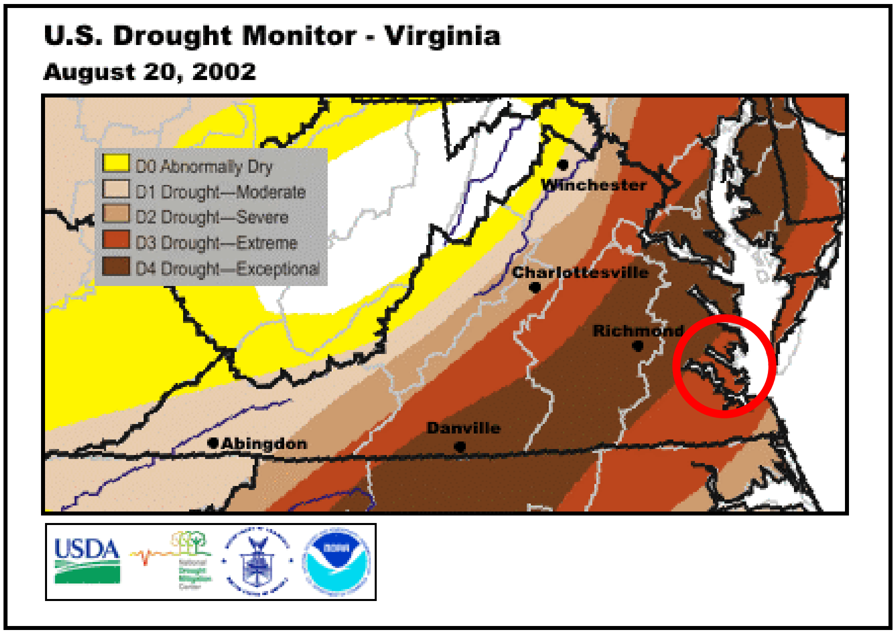
Since the early 1900s, there have been six major droughts that have affected the communities on the Peninsula. The drought of 1930-32 was one of the most severe droughts recorded in the region. The droughts of 1938-42 and 1962-71 were less severe; however, the 1962-71 drought had an extreme duration. The droughts of 1980-82 and 1998-99 were the least severe for the state; however, the drought of 1998-99 hit the communities of the Peninsula region particularly hard. The drought of 2000-2002 was felt statewide, and is considered the most significant since the 1930-32 event. (Sammler, 2005)

The drought of 1930-32 had a tremendous effect on Virginia. Numerous rivers completely dried up, crops were totally destroyed, drinking water was difficult to find, forest fires burned approximately 300,000 acres of land (over 30 times the current annual average) and average summer temperatures were in the low 100's. After adjusting for inflation, the estimated losses for this drought were $1 billion. If the same drought were to occur in Virginia today, the devastation would be much greater due to an increased population and demand for water resources.

The drought of 1998-99 had a particularly hard impact on the Peninsula. The region received some of the lowest rainfall totals in over 120 years. This led to decimated crops and depletion of water and feed reserves, as well as a number of brush fires. Many stream-gauging stations reported streamflow at or below 10 percent of the normal flow. On December 1, 1998, the

Governor declared a state of emergency and requested federal aid. Losses in the region grew to nearly $190 million. During August of 1999, NOAA ranked the Peninsula area in a moderate to severe drought.

Figure 4.1.11- U.S. Drought Monitor, August 20, 2002



Following shortly on the heels of the 1998-99 drought, the designated drought of 2000-2002 reached its height in late summer, early fall of 2002. The Virginia Drought Monitoring Task Force, a consortium of interested state and Federal agencies, provided Drought Status Reports on a monthly basis between June and November 2002. Conditions deteriorated quickly in the first two weeks of August 2002, and the U.S. Drought Monitor indicated an "Extreme Drought" for the Peninsula (see Figure 4.1.11) by August 20th. Drought indicators were numerous and severe: record minimum flows on the James and York Rivers, continually declining groundwater levels, declining reservoir levels, short or very short topsoil moisture conditions across 82 percent of the Commonwealth, numerous ozone advisories, and higher than normal wildfire activity. For the Tidewater area, normal one-year precipitation for the period September 2001 to August 2002 was 41.17 inches. By August 20, 2002, the one-year precipitation was only 29.35 inches, a 71-percent departure from normal. Newport News Waterworks customers were under voluntary conservation measures beginning July 25, with the reservoir at 71 percent capacity. James City Service Authority Central System instituted voluntary measures, as well. The Waller Mill Reservoir serving Williamsburg dropped 27 inches below the spillway, and voluntary conservation measures went into effect on March 20, 2002. Williamsburg was purchasing water from Newport News Waterworks in July. By November 2002, much of the Peninsula area had returned to normal conditions due to rainfall after September 1st.

4.1.12 Earthquakes

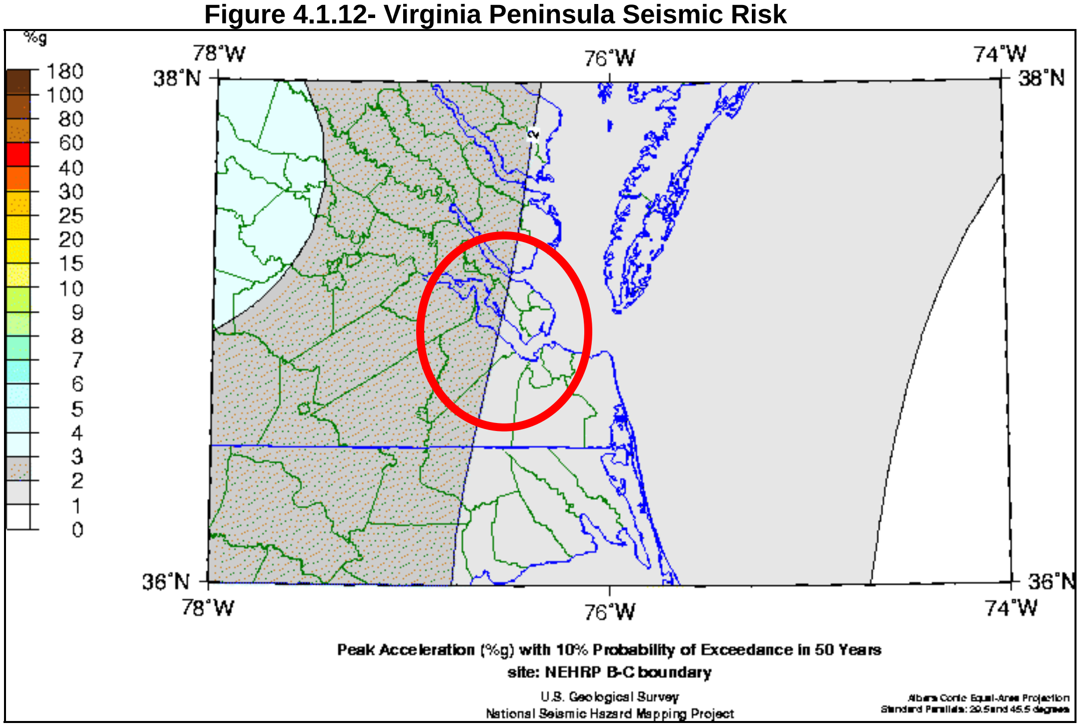
The earth's outer surface is broken into pieces called tectonic plates, which move away from, towards or past each other. Because the continents are part of these plates, they also move. An earthquake occurs when the stresses caused by plate movements are released. The abrupt release of stored energy in the rocks beneath the earth's surface results in a sudden motion or trembling of the earth. The epicenter is the point on the Earth's surface directly above the source of the earthquake.

Smaller earthquakes occur much more frequently than large earthquakes. These smaller earthquakes generally cause little or no damage. However, very large earthquakes can cause tremendous damage and are often followed by a series of smaller aftershocks lasting for weeks after the event. This phenomenon, referred to as 'minor faulting,' occurs during an adjustment period that may last for several months.

Virginia and the eastern side of the North American continent are in the middle of a tectonic plate. The states east of the Mississippi River have fewer earthquakes than the western portion of the country. Quakes occurring in the west are typically stronger, but eastern earthquakes can cause more damage away from their origin because the underlying bedrock is well-connected (like a concrete slab). This geology allows eastern earthquakes to travel farther than in the west, where the underlying topography is so disconnected (like a brick patio) that the energy of a quake is dissipated closer to the epicenter.

According to the Virginia Department of Mines, Minerals and Energy, Virginia has a moderate earthquake risk (similar to most states on the eastern seaboard). This risk assessment is further supported by the USGS. The USGS rates areas of the United States for their susceptibility to earthquakes based on a two or ten percent probability of a given peak force, being exceeded in a 50 year period. Based on the map shown in Figure 4.1.12, the Virginia Peninsula lies in an area of moderate seismic risk, with a 10% chance in the next 50 years that a peak acceleration of one to three percent g will be equaled or exceeded.

Figure 4.1.12- Virginia Peninsula Seismic Risk



The Richter magnitude scale was developed in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. Adjustments are included for the variation in the distance between the various seismographs and the epicenter of the earthquakes. On the Richter Scale, magnitude is expressed in whole numbers and decimal fractions. For example, a magnitude 5.3 might be computed for a moderate earthquake, and a strong earthquake might be rated as magnitude 6.3. Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude; as an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31 times more energy than the amount associated with the preceding whole number value.

The effect of an earthquake on the Earth's surface is called the intensity. The intensity scale consists of a series of certain key responses such as people awakening, movement of furniture, damage to chimneys, and finally, total destruction. Although numerous *intensity scales* have been developed over the last several hundred years to evaluate the effects of earthquakes, the one currently used in the United States is the Modified Mercalli Intensity (MM) Scale. It was developed in 1931 by the American seismologists Harry Wood and Frank Neumann. This scale, composed of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction, is designated by Roman numerals. It does not have a mathematical basis; instead it is an arbitrary ranking based on observed effects.
The Modified Mercalli Intensity value assigned to a specific site after an earthquake has a more meaningful measure of severity to the nonscientist than the magnitude because intensity refers to the effects actually experienced at a particular place.

The lower numbers of the intensity scale deal with the manner in which people feel the earthquake. The higher numbers of the scale are based on observed structural damage. Structural engineers usually contribute information for assigning intensity values of VIII or above. The following is an abbreviated description of the 12 levels of Modified Mercalli intensity:

Table 4.1.12a- Modified Mercalli Intensity Scale

Level	Description
I	Not felt except by a very few under especially favorable conditions.
II	Felt only by a few persons at rest, especially on upper floors of buildings.
III	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
XII	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Historically significant Virginia earthquakes were first recorded in 1774. Virginia has had over 160 earthquakes since 1977, of which 16 percent were felt. This equates to an average of one earthquake occurring every month with two felt each year (VTSO, 2005). On February 21, 1774, a strong earthquake was felt over much of Virginia and southward into North Carolina. Many houses were moved considerably off their foundations at Petersburg and Blandford (intensity MM VII). The shock was described as "severe" at Richmond and "small" at Fredericksburg. However, it "terrified the inhabitants greatly." The total felt area covered about 57,900 square miles.

The three great earthquakes near New Madrid, Missouri, in 1811 - 1812 (December 11th, January 23rd, and February 7th) were felt strongly in Virginia. Reports from Norfolk and Richmond newspapers describe the effects in detail.

An earthquake, apparently centered in southwestern Virginia, on March 9, 1828, was reported felt over an area of about 218,090 square miles, from Pennsylvania to South Carolina and the Atlantic Coastal Plain to Ohio. Very few accounts of the shock were available from places in Virginia; it was reported that doors and windows rattled (MM V). President John Quincy Adams felt this tremor in Washington D.C., and provided a graphic account in his diary. He compared the sensation to the heaving of a ship at sea.

The August 27, 1833, earthquake covered a broad felt area from Norfolk to Lexington and from Baltimore, Maryland, to Raleigh, North Carolina - about 52,110 square miles. Two miners were killed in the panic the shock caused at Brown's Coal Pits, near Dover Mills, about 18 miles from Richmond. At Charlottesville, Fredericksburg, Lynchburg, and Norfold, windows rattled violently, loose objects shook, and walls of buildings were visibly agitated (MM V).

Another moderately strong widely felt shock occurred on April 29, 1852. At Buckingham and Wytheville, chimneys were damaged (MM VI). The felt area extended to Washington D.C., Baltimore, Maryland, and Philadelphia, Pennsylvania, and also included many points in North Carolina - approximately 162,120 square miles. This pattern was repeated on August 31, 1861. The epicenter was probably in extreme southwestern Virginia or western North Carolina. At Wilkesboro, North Carolina, bricks were shaken from chimneys (MM VI). The lack of Virginia reports may perhaps be ascribed to the fact that the Civil War was under way and there was heavy fighting in Virginia at the time. This shock affected about 299,150 square miles and was felt along the Atlantic coast from Washington, D.C., to Charleston, South Carolina, and westward to Cincinnati, Louisville, and Gallatin, Tennessee, and southwestward to Columbus, Georgia.

A series of shocks in quick succession disturbed the eastern two-thirds of Virginia and a portion of North Carolina on December 22, 1875. At Manakin, many chimneys were broken and shingles on one store were shaken off (MM VII). Damage to chimneys was reported from other places in Goochland and Powhatan Counties. At Richmond, the shock, which was accompanied by a rumbling noise, was severe and lasted from 20 to 30 seconds; plaster fell and several panes of window glass broke. There was general alarm in all parts of the city; many people ran out of their houses in fright. The total felt area was about 50,180 square miles.

The famous 1886 earthquake in Charleston, South Carolina was felt on the Virginia Peninsula, and the Hampton Roads region. Plaster damage in Williamsburg, as well as broken chimneys in nearby Norfolk were typical of impacts throughout the Commonwealth. In Norfolk, light framework was thrown down, large warehouses were damaged, and the earthquake caused panic in the Opera House. The event led to reports of nausea among many residents of Norfolk, and had an estimated magnitude of 6.6 to 6.9, and was felt as far north as Canada and as far south as Cuba. Residents of Missouri also felt the earthquake.

The largest earthquake to originate in Virginia is historic times occurred on May 31, 1897. The epicenter was in Giles County, where on May 3rd, an earlier tremor at Pulaski, Radford, and Roanoke had caused damage (MM VI). Loud rumblings were heard in the epicentral region at various times between May 3rd and 31st. The shock on the latter date was felt from Georgia to Pennsylvania and from the Atlantic Coast westward to Indiana and Kentucky, an area covering about 279,850 square miles. It was especially strong at Pearisburg, where the walls of old brick houses were cracked and bricks were thrown from chimney tops. Springs were muddied and a few earth fissures appeared (MM VIII). Chimneys were shaken down at Bedford City, Houston, Pulaski, Radford, and Roanoke. Chimneys were also broken at Raleigh, North Carolina, Bristol and Knoxville, Tennessee, and Bluefied, West Virginia. Minor tremors continued in the epicentral region from time to time until June 6th; other disturbances felt on June 28th, September 3rd, and October 21st were probably aftershocks. On February 5, 1898, the residents of Pulaski reported additional chimney damage (MM VI). In Newport News, there were reports that the earthquake "frightened a great many people." The shake was more perceptible "near the edge of the water, where it caused the piers and buildings to rock," but no damage was reported. In Williamsburg, the earthquake was felt by "nearly everybody in town.". (VTSO 2005)

An earthquake on February 11, 1907, caused minor damage at Arvonia, Ashby, and Buckingham. At Arvonia, many people became terrified and ran from their houses (MM VI); although no damage was reported from Columbia, many ran from their homes. The felt area was small, approximately 5600 square miles. Other shocks of lesser intensity occurred in the same area on August 23, 1908, and May 8, 1910.

The Shenandoah Valley region was strongly shaken by an earthquake on April 9, 1918. It was called the "most severe earthquake ever experienced" at Luray. Although little damage resulted, people in many places over the northern valley region were greatly alarmed and rushed from their houses (MM VI). Broken windows were reported at Washington, D.C. President Wilson and his family at the White House noticed the tremor; the President's secretary called a newspaper office to learn the cause of the terrifying noise. The felt area extended over 60,000 square miles, including parts of Maryland, Pennsylvania, and West Virginia. Another shock on September 5, 1919, was felt in the same general region, although the total affected area was much smaller. It was strongest in the Blue Ridge Mountains south of Front Royal. At Arco, plaster fell and some chimneys were damaged (MM VI). Springs and streams were muddied in the epicentral area.

On December 26, 1929, a moderate shock at Charlottesville shook bricks from a few chimneys (MM VI). It was reported felt in various parts of Albemarle County. A number of newspaper accounts gave the date of this earthquake as December 25th. Giles County was strongly shaken again on April 23, 1959. At Eggleston and Pembroke, several chimneys were damaged, plaster cracked, and pictures fell from walls (MM VI). A wide area (about 2,900 square miles) of southwestern Virginia felt the tremor; a few places in West Virginia also reported the shock. (USGS 2005)

The April 23, 1959 earthquake was strongest in Giles County, at Eggleston and Pembroke. Residents there reported several damaged chimneys and articles shaken from shelves and walls. One chimney toppled at the Norfolk and Western Station in Eggleston. The quake was also felt in West Virginia.

An earthquake in southwest Virginia on November 11, 1975 broke windows in the Blacksburg area of Montgomery County, and plaster cracked at Poplar Hill. The quake was also felt in Pulaski County. Another southwest Virginia event on September 13, 1976 was observed in many towns in North Carolina and Virginia and in a few towns in South Carolina and West Virginia. Bricks fell from chimneys and pictures fell from walls in Surry County at Mount Airy, N.C. At the nearby town of Toast, N.C., cracks formed in masonry and plaster. (VTSO 2005)

The *Daily Press* and *Virginian-Pilot* newspapers reported a minor, but relatively rare, earthquake with its epicenter on the Peninsula August 3, 1995. According to the *Virginian-Pilot*, the quake measured 2.6 on the Richter scale. The Virginia Tech Seismological Observatory detected the quake with instrumentation in Goochland County west of Richmond, and in Blacksburg. The quake was centered under the York River near York River State Park. According to the *Daily Press*, people at Camp Peary reported feeling the quake.

The December 9, 2003 Powhatan County earthquake was a complex event consisting of two sub-events occurring 12 seconds apart. Slight damage (MM VI) was reported at Bremo Bluff and Kents Store. The event was felt (MM V) at Columbia, Fork Union, Goochland, Oilville, Rockville and Sandy Hook; (MM IV) at Appomattox, Amelia Court House, Amherst, Blackstone, Bumpass, Charlottesville, Chester, Chesterfield, Colonial Heights, Cumberland, Dillwyn, Farmville, Glen Allen, Lawrenceville, Louisa, Manakin Sabot, Mechanicsville, Midlothian, Mineral, Palmyra, Petersburg, Powhatan, Richmond, Scottsville and Spotsylvania; (MM III) at Alexandria, Fairfax, Falls Church, Fredericksburg, Lexington, Lynchburg, McLean, Roanoke, Staunton and Vienna. It was also felt (MM III) at Bethesda, Rockville and Silver Spring, Maryland and at Rocky Mount and Winston Salem, North Carolina. Felt (MM II) at Chapel Hill, Greensboro and Raleigh, North Carolina and at Washington, DC. Felt in much of Maryland and Virginia and in north-central North Carolina and a few areas of Delaware, New Jersey, New York, Pennsylvania and West Virginia.
A summary of collected data for historical, significant and recent earthquakes in the region is provided in Table 4.1.12. Because the data was gathered from a variety of sources, all indicators are not available for each event.

Table 4.1.12b -Summary of Virginia Earthquake Data

Year	Location	Focus Depth (km)	Deaths	Damage ($)	Richter Scale Magnitude	MMI	Felt Area (square miles)
1774	Near Petersburg	not available	0	0	4.5	6	58,000
1828	Location not recorded	not available	0	0	4.6	5	
1833	Central Virginia	not available	0	0	4.5	5	52,000
1852	Near Wytheville	not available	0	0	4.8	6	174,500
1852	Central Virginia	not available	0	0	4.3	6	32,000
1853	Location not recorded	not available	0	0	4.6	5	
1875	Central Virginia	not available	0	0	4.8	7	50,000
1885	Nelson County	not available				6	25,000
1897	Giles County	not available	0	0	5.6	8	280,000
1897	Southwest Virginia	not available	0	0	4.3	6	89,500
1898	Pulaski	not available	0	0	4.4	6	34,000
1898	Location not recorded	not available	0	0	4.5	5	
1899	Location not recorded	not available	0	0	4.5	5	
1907	Near Arvonia	not available	0	0	4	6	5,600
1918	Luray	not available	0	0	4.6	6	65,000
1919	Near Front Royal	not available	0	0	0	6	
1929	Charlottesville	not available	0	0	3.7	6	1,000
1954	Lee County	not available				6	
1959	Giles County	1	0	0	3.9	6	2,050
1969	Rich Creek					6	100,000
1975	Southwest Virginia	1	0	0	3.2	6	
1976	Southwest Virginia	9	0	0	3.3	6	9,000
1991	Virginia	18	0	0	0	5	
1995	York River	not available	0	0	2.6	not available	
1997	Near Culpeper	not available	0	0	2.5	not available	
1997	Near Manassas	not available	0	0	2.5	not available	
1997	Near Galax	not available	0	0	2.2	not available	
1998	Near Dillwyn	not available	0	0	3.8	not available	
2001	Shadwell, east of Charlottesville	not available	0	0	3.2	not available	
2003	30 miles SE of Charlottesville	not available	0	0	3.9	not available	
2003	Near Ashland	not available	0	0	2.6	not available	
2003	Powhatan County	< 5	0	0	4.5	6	~22,500

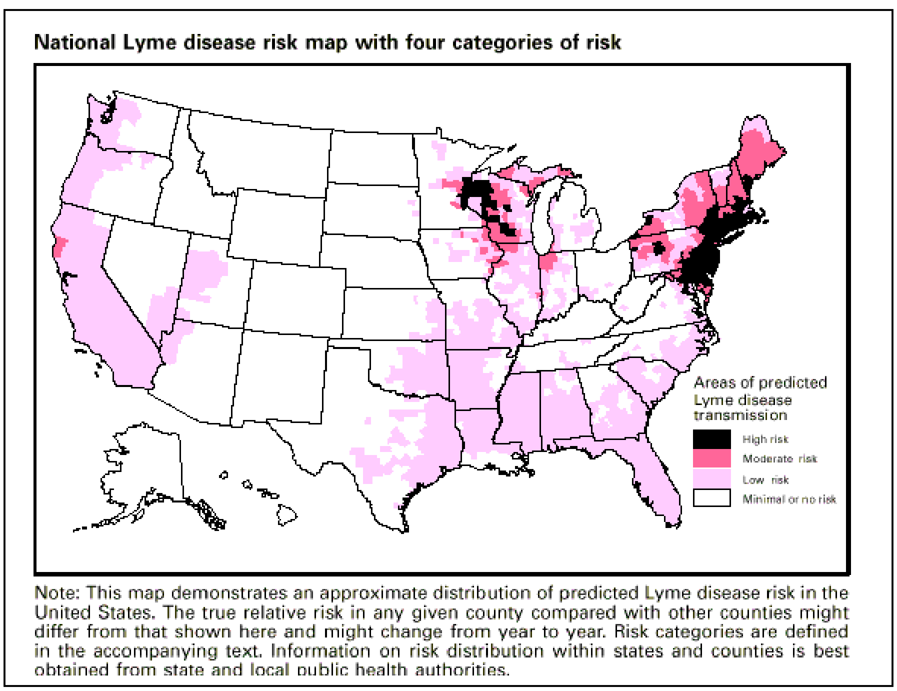
Sources: USGS, National Atlas, 30 June 1999
Daily Press and *Virginian-Pilot*, August 4, 1995
USGS Significant Earthquakes of the World for 2003 web site
Washington Post, December 10, 2003

4.1.13 Biological Hazards/Epidemics

Biological hazards originate from naturally occurring substances such as bacteria, fungi, molds and viruses. In many cases these hazards are not visible, yet they can cause serious health effects to humans, plants and animals. West Nile Virus, Lyme disease, and bacterial epidemics have all been documented in the Peninsula region within the last ten years.

West Nile Virus (WNV) was first reported in the United States in 1999. Since then, almost 10,000 people have fallen ill across the country. WNV is transmitted to humans through mosquito bites and usually causes little reaction. However, a small percentage of those infected develop mild symptoms that include fever, headache, body aches, skin rash, and swollen lymph glands. Less than one percent of infected people develop a more severe illness that can include meningitis (inflammation of one of the membranes covering the brain and spinal cord) or encephalitis. The Peninsula communities have taken a proactive stance against WNV by attempting to eliminate mosquito populations and breeding grounds, especially those created by trees felled during Hurricane Isabel. Some of the techniques used are low volume spraying, draining areas of standing water, and introducing mosquito-eating fish. Additionally, York County coordinates with the Virginia Department of Transportation (VDOT) to maintain easements and right-of-ways that contain standing water. According to the Virginia Department of Health, there were 101 positive WNV cases for animals (birds, horses, and mammals) in the Peninsula region from 2000 to 2003. There was one probable case of human WNV in the City of Newport News in 2003.

Figure 4.1.13 -National Lyme Disease Risk Map



Source: CDC 2004

Lyme disease is a bacterial infection that can afflict humans and animals. It is most commonly transmitted to humans bitten by deer ticks. If Lyme disease goes untreated, some patients may develop arthritis, including intermittent episodes of swelling and pain in the large joints; neurological abnormalities, such as meningitis, facial palsy, motor and sensory nerve inflammation and encephalitis; and cardiac problems, such as an enlarged heart and inflammation of the heart tissue. The Peninsula region is an area of low risk for Lyme disease transmission, according to the Centers for Disease Control and Prevention (CDC 2004); see Figure 4.1.13. In 2002, the CDC reported 259 cases of Lyme disease (out of 23,763 nationwide) in Virginia.

Bacteria and viruses can cause water contamination and have disastrous effects on the animals living within polluted waterways. In some instances, pollution from storm flooding and combined sewer overflow may produce high levels of fecal coliform bacteria and viruses in rivers and drinking water. The Poquoson River, Chisman Creek, Patrick's Creek, Lambs Creek, Roberts Creek, and Lyons Creek are all listed as bacteria impaired water body segments on the VDEQ’s 2003-2004 Total Maximum Daily Load schedule.

4.1.14 Landslide

Landslides constitute a major geologic hazard because they are widespread, occurring in all 50 states. Landslides cause $2 billion in damage annually and more than 25 fatalities on average each year (USGS 2003). Landslides can and do occur in conjunction with other natural hazards, such as heavy rain events and earthquakes or human activities like excavations. Landslides can be broken down into falls, flows, or slides based on the type of earth movement (USGS 2003).

Most of the Peninsula area is classified as low landslide risk on the Landslide Incidence and Susceptibility Map (USGS 2001). There are however small areas that are listed as Moderate. These areas occur in Hampton, James City County, Newport News, and York County (see Appendix B for Landslide Hazard Map). The data used to generate these maps (USGS 2001) was highly generalized; therefore, further investigation at the local level is recommended.

4.1.15 Expansive Soils

Soils with a sufficient content of certain types of clay experience a change in volume during a transition from dry to wet conditions. These soils are called expansive soils, or “shrink-swell” soils. Hazards associated with expansive soils arise from the change in volume experienced. This physical factor can result in slope instability and cause damage to building foundations. Each community within the Peninsula region addresses the issue of expansive clay in their respective comprehensive plans, and addresses soil conservation based on state standards set forth in the Virginia Erosion and Sediment Control Law and Regulations.

4.1.16 Tsunami

"Tsunami" is a Japanese word meaning "harbor wave” and is a water wave or a series of waves generated by an impulsive vertical displacement of the surface of the ocean or other body of water (NOAA 2005b). A tsunami can occur when a series of ocean waves are generated by a sudden displacement in the sea floor, landslides, or volcanic activity. In the ocean, the tsunami wave may only be a few inches high. The wave may come gently ashore or may increase in height to become a fast moving wall of turbulent water several meters high (NOAA 2005a).

Tsunamis, commonly called seismic sea waves-or incorrectly, tidal waves, have been responsible for at least 470 fatalities and several hundred million dollars in property damage in the United States and its territories. These events are somewhat rare and major tsunamis occur in the Pacific Ocean region only about once per decade (NOAA 2005b).

Tsunamis have occurred only rarely along the Atlantic Coast. The National Geophysical Data Center (NGDC) administered by NOAA maintains a database of worldwide tsunami events recorded since 2000 B.C. According to the NGDC database, there have been 39 events along the North American Atlantic coast that have generated tsunamis.

According to the most recent data, in order for a tsunami to impact the East Coast, an earthquake with a magnitude of 9.0 or greater would need to take place north of Puerto Rico. Although the chances of a tsunami impacting the coast are minute, it could potentially produce waves from four to six feet along the coast. (Sammler, 2005) Klaus Jacob of the Lamont-Doherty Earth Observatory in New York estimated that a tsunami "has a lower than 1 in 1000 chance of occurring in eastern North America in any given year" (Boston Globe, 2004).

Because of the irregularity of the Peninsula's coastline, a tsunami's effects would vary geographically. Along the Chesapeake Bay coastline, the effect would be similar to that of a nor'easter at high tide, with shoreline erosion and damage to docks and piers. Other effects would be beach erosion, dune and seawall overwash, coastal flooding and damage to low-lying properties. Along inner creeks and rivers that narrow in width inland, flooding would be amplified as the wave is confined to a more narrow space (MGS, 2005).

Although earthquake-driven tsunamis pose some risk to the Peninsula, another source of tsunami action exists closer to home. Driscoll and others (2000) documented a large submarine landslide off the coast of Virginia. The Albemarle-Currituck Slide occurred approximately 18,000 years ago, involving over 33 cubic miles of material which slid seaward from the edge of the continental shelf, most likely causing a tsunami. Cracks in the continental shelf exist in this area, which may indicate slope failure and potential for another submarine landslide and subsequent tsunami of several meters in height. Impacts from a tsunami of this height would be similar to storm surge from a Category 3 or 4 hurricane.

4.1.17 Sea Level Rise

While not specifically called out in discussions with the PHMPC when identifying the natural hazards that the Peninsula faces, sea level rise can be expected to have an impact, over time, in the region. Because much of the coastal land area in the region lies at elevations at or below 7 feet MSL, any increase in the mean low water level of the Chesapeake Bay and surrounding tidal rivers and estuaries has a direct impact on coastal lands. These impacts may include the potential for increased erosion, loss of coastal zone lands, including wetlands, and a potential for increased damages from coastal storms.

Research conducted by NOAA indicates that, during the period 1854 to 1999, sea level in the Chesapeake Bay region has risen from 1.30 to 1.45 feet (NOAA 2001). The rising sea level trend is attributed to two primary sources: a slow, gradual rise in ocean levels, and land subsidence caused primarily by natural geologic processes and, in localized areas, by groundwater withdrawal (Boesch *et al*, undated). By weighing the impact of future potential sea level rise, as well as the future storm impacts when making future land use decisions, the region has the opportunity to take a more proactive approach to regulatory protections. Sea level rise can be expected to continue through the foreseeable future, which warrants continued vigilance at the local level; however, reducing the rate of sea level rise is outside the realm of local control (Boesch *et al*, undated).

Protecting tidal structures and wetlands may mean more active management at the local level, including techniques to ensure adequate elevation of structures and adequate erosion and sediment control measures. FEMA estimates that at the rate of sea level rise experienced on average around the coastal United States, roughly 12 inches per century, the number of households subject to flooding would increase from about 2.7 million now to almost 6 million by 2100 as a result of the combination of sea level rise and projected coastal population growth (Office of Technology Assessment, 1993). Over time, sea level may also change the physical characteristics of the region's floodplains. One way in which Peninsula communities may wish to address this gradual threat is by examining floodplain management ordinances to consider the inclusion of a one-foot or more freeboard requirement for new development or substantial improvements in the floodplain.

Sea level rise further exacerbates coastal erosion by causing the boundary between land and water to recede and move inland.

4.1.18 Critical vs. Non-critical Hazards

Based on readily available data, local knowledge, and observations, the PHMPC performed a two-stage evaluation of above-mentioned hazards utilizing the Natural Hazard Ranking Sheet (Appendix D). First, they grouped the hazards into two categories: critical and non-critical hazards (Table 4.1.17).

> **Critical hazards:** those hazards in which historical data exist to document impacts that have resulted in significant losses to the Peninsula region and its citizens. Critical hazards are those natural hazards that occur with little or no warning and have the possibility to create such widespread destruction that resources from outside the jurisdiction would be required to respond or recover.
>
> **Non-critical hazards:** those hazards that have occurred very infrequently or have not occurred at all in the historical data. They are not considered a widespread threat resulting in significant losses of property or life. Non-critical hazards also include hazards that occur frequently (on average every year) and those that the jurisdiction is equipped to mitigate.

Secondly, the PHMPC, in conjunction with the consulting team, ranked each critical hazard based on the threat posed to its citizens (Table 4.1.17). Hazards that ranked critical with a medium to high hazard level were then investigated further and a vulnerability analysis was performed for affected communities.

Table 4.1.18 -Hazard Identification Results

Hazard type	Non-Critical/Critical	Hazard Level
Flooding	Critical	High
Hurricanes	Critical	High/Medium
Tornados	Critical	Medium
Wildfire	Critical	Medium
Nor'easters	Critical	Medium/Low
Winter storms	Critical	Medium/Low
Drought	Non-Critical	Low
Earthquakes	Non-Critical	Low
Biological Hazards/Epidemics	Non-Critical	Low
Thunderstorms	Non-Critical	Low
Dam Failure	Non-Critical	Low
Extreme Heat	Non-Critical	Low
Expansive Soils	Non-Critical	Low
Landslides	Non-Critical	Low
Sea Level Rise	Non-Critical	Low
Tsunamis	Non-Critical	Low